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Comparison of Pilot Data with Predictions from the U.S. EPA (Environmental Protection Agency) SPRAYMOD Computer Program

Tennessee Univ., Knoxville

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16. ABSTRACT The report compares SO2 removal predictions of the EPA-developed SPRAYMOD computer program with 12 different data sets collected at the University of Tennessee with a 1000 cfm (28.3 cu m/min) lime spray dryer operating without recycling of the baghouse collected solids. The experimental results were obtained with spray dryer operating conditions of: SO2 concentration, 633-3178 ppm; inlet gas temperature, 123-171 C (254-339 F); and approach to saturation, 8-20 C (14-36 F). The predicted SO2 removal efficiency depended on SO2 concentration and/or slurry concentration as well as the user's choice of the model reaction rate coefficient (KR). For large KR (>100,000 cc/mole-s), both the backmix and plug flow models were insensitive to most operating conditions and overpredicted the observed efficiency. With KR = 0, the plug flow model predicted lower efficiency, and its sensitivity to operating conditions more closely approached that seen in the pilot spray dryer. Detailed analyses of predicted vs. measured efficiencies indicated the model (KR = 0) to be less sensitive to lime slurry concentration and SO2 concentration than the observed performance. The model underpredicted efficiency at low slurry concentrations and overpredicted efficiency at high slurry concentrations. Recommendations for improving the model are suggested.

17. KEY WORDS AND DOCUMENT ANALYSIS

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COMPARISON OF PILOT PLANT DATA WITH PREDICTIONS FROM THE U.S. EPA SPRAYMOD COMPUTER PROGRAM

by

Wayne T. Davis
Gregory D. Reed
George P. Partridge
Civil Engineering Department
The University of Tennessee
Knoxville, TN 37996

Purchase Order No. 5D2270NAEX

EPA Project Officer:
Theodore G. Brna
Air and Energy Engineering Research Laboratory
Gas Cleaning Division
Research Triangle Park, N.C. 27711

AIR AND ENERGY ENGINEERING RESEARCH LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
RESEARCH TRIANGLE PARK, NC 27711

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ABSTRACT

The use of computer models for sulfur dioxide (SO_2) removal processes allows the user to predict conditions which may not have been tested in spray dryer/fabric filter applications. This report presents a comparison of the U.S. EPA developed SPRAYMOD computer program with a series of 12 different data bases collected at the University of Tennessee on a 1000 acfm spray dryer utilizing a calcium hydroxide [$Ca(OH)_2$] slurry. Results are presented from a variety of operating conditions for the spray dryer without recycle, including:

SO_2 concentration:	633-3178 ppm
Inlet temperature:	123-171°C (254-339°F)
Approach to saturation (AT):	8-20°C (14-36°F)

Graphical comparisons of the observed efficiency versus stoichiometric ratio are presented for each data base and compared to the model-predicted values. The report also includes a summary of the data bases which may be used for other modeling efforts.

This report has been reviewed in accordance with the U.S. Environmental Protection Agency's peer and administrative review policies and approved for presentation and publication.

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SECTION 1

INTRODUCTION

The use of computer models for sulfur dioxide (SO_2) removal processes allows the user to predict conditions which may not have been tested in spray dryer/fabric filter applications. This report presents a comparison of the U.S. EPA developed SPRAYMOD computer program with a series of 12 different data bases collected at the University of Tennessee on a 1000 acfm[a] spray dryer utilizing a calcium hydroxide [$Ca(OH)_2$] slurry. Results are presented from a variety of operating conditions for the spray dryer without recycle, including:

SO_2 concentration:	633-3178 ppm
Inlet temperature:	123-171°C (254-339°F)
Approach to saturation (AT):	8-20°C (14-36°F)

The SPRAYMOD computer program is a simulation program which mathematically models the removal of SO_2 in a spray dryer. The model developed by Research Triangle Institute under contract to EPA is a simultaneous heat and mass transfer model which predicts the simultaneous evaporation of a droplet and the absorption/reaction of SO_2 with $Ca(OH)_2$ in the evaporating droplet. The SO_2 removal is modeled by two different mechanisms corresponding to wet and dry particle stages. A bulk volume reaction rate coefficient (KR) for the entire droplet/particle is used for the dry particle stage. The model includes the dissolution kinetics of the $Ca(OH)_2$ particles within the droplet and has both backmix and plug flow reaction options.

---

[a]Multiplicative conversion factors to obtain the International System of Units (SI) are given in Appendix A.

The pilot spray dryer/baghouse test facility used a slipstream of the University of Tennessee's stoker fired boilers. The pilot plant system consisted of a slaking system, control room, a 7 ft diameter spray drying chamber with a variable speed Stork-Bowen AA-6 spray machine (5,000 - 21,000 rpm), and a 6 in. diameter centrifugal atomizer with six nozzle inserts. A baghouse was used to collect the product leaving the spray dryer and was periodically cleaned as required to minimize the pressure drop.

After conducting preliminary sensitivity analyses of the model and determining appropriate internal conditions for operation of the model, data analyses were conducted by comparing the measured efficiency versus stoichiometric ratio curve for each data base to the model predicted efficiency versus stoichiometric ratio curve.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

The ability of SPRAYMOD to predict measured efficiencies was observed to be dependent on the operating conditions of SO_2 concentration and/or slurry concentration as well as the user's choice of the model reaction rate coefficient (KR). Both the backmix and plug flow models were observed to be relatively insensitive to most operating conditions when a large value of KR ($> 10^5$ cm^3 / mole-s) was assumed, and tended to over-predict the observed efficiency of the spray dryer. When KR was assumed to be zero, the plug flow model predicted lower efficiencies and became more sensitive to the operating conditions as had been observed in the pilot plant.

Detailed comparative analyses were conducted of the predicted versus measured efficiencies for an assumed value of KR=0. Under this condition, the model was still observed to be less sensitive to the effect of slurry concentration and SO_2 concentration than the observed data. The model tended to under-predict at low slurry concentrations and over-predict at high slurry concentrations. This conclusion suggests that there is a

lack of sensitivity in the model to handle the change in $Ca(OH)_2$ dissolution and/or diffusion rate of reactants in the slurry droplet resulting from changes in the slurry concentration.

It is recommended that further development work be conducted to improve the model's ability to simulate spray dryer performance. Specifically work needs to be done to modify the dissolution equations in the model to account for potential effects of slurry concentrations on the dissolution of $Ca(OH)_2$ particles and diffusion of SO_2 and calcium in the spray dryer slurry droplets. In addition, appropriate values of KR need to be determined and included as a function of moisture content in the model, eliminating the need for assuming a value of KR.

SECTION 3

DESCRIPTION OF/AND OPERATIONAL PROCEDURES FOR THE SPRAY DRYER PILOT PLANT TEST FACILITY

3.1 EXPERIMENTAL DESCRIPTION OF PILOT PLANT

Figure 1 is a schematic diagram of the pilot test facility which was constructed in 1980 on a slipstream of the University of Tennessee's stoker-fired boilers. The original pilot plant system consisted of a slaking system control room, a 7 ft diameter spray drying chamber with a variable speed Stork-Bowen AA-6 Spray machine (5,000-21,000 rpm), and a 6 in. diameter centrifugal atomizer with six nozzles inserts. A low energy shaker baghouse with four 12 in. x 32 ft fiberglass filter bags (bottom entry) was utilized downstream from the spray dryer for particulate control. In July 1984, the shaker baghouse was replaced by a 36 bag pulse jet collector (off-line clearing) with 4.5 in. x 12 ft fiberglass filter bags.

A continuous pneumatic recycle system was installed in 1983 for use in recycle testing. This system provided continuous partial recycle of the dried products from the spray dryer and baghouse. The dried products were pneumatically conveyed to cyclone separators, collected in screw feeders, and partially recycled back in the slurry feed as

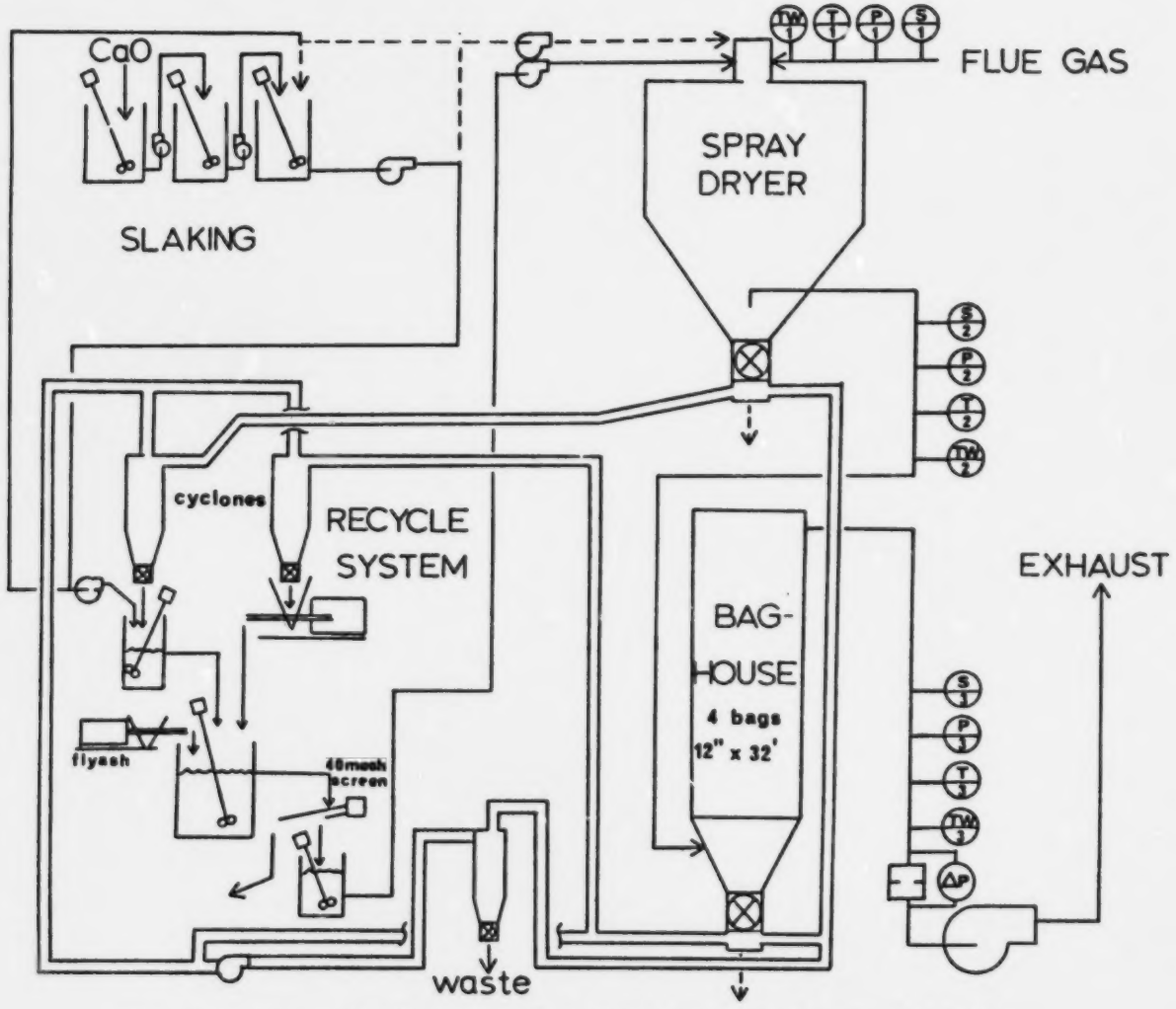

Figure 1. Schematic diagram of the pilot spray dryer/baghouse facility.

needed to satisfy test requirements. The baghouse was periodically cleaned as required to minimize pressure drop across the baghouse. The lime feed, spray dryer recycle solids and baghouse recycle solids, were mixed in an intermediate mixing tank, and the resulting slurry screened through a 420 µm vibrating screen prior to delivery to the atomizer. This technique was found to be necessary for successful operation at concentrations of 15-35% solids to prevent clogging of the slurry lines and atomizer nozzles due to the small volumetric flow rate of the delivery system (less than 0.30 gpm with 0.25 in. ID lines). Further it was found necessary to continuously recycle the lime slurry between the final slaking room mixing tank and the recycle tanks located at the spray dryer in order to prevent plugging in the transport lines when the atomizer feed rate was terminated. In the testing reported here, no recycle data are included; hence, the recycle transport system was not operated.

System instrumentation provided for continuous monitoring of the static pressure, temperature, and SO_2 concentrations at the inlet and outlet of both the spray dryer and the baghouse. Sampling locations for these are indicated in Figure 1 by the symbols P, T, and S, respectively. Continuously extracted samples of flue gas were transported through heat-traced lines to one of the analyzers: two Lear-Siegler SM810 analyzers and a TECO Model 800/Model 40 gas condition/analyzer for SO_2 analysis. Depending on the availability of analyzers, data were acquired simultaneously at multiple ports or sequentially. Wet bulb temperatures were measured at all three ports by a hand-held wetted-wick thermometer and/or thermocouple (symbol TW in Figure 1).

Temperature was controlled by a dilution air damper located upstream of the inlet sampling port of the spray dryer. The concentration of SO_2 was maintained by controlled supplemental injection of SO_2.

3.2 TEST PROCEDURES FOR SPRAY DRYER TESTING

All data reported here represent individual tests of 45 minutes to 1 hour duration. A single 1 hour evaluation consisted of monitoring 18 different parameters at the pilot plant including atomizer disk speed, SO_2 concentrations at Ports 1-3, temperatures at Ports 1-3, available CaO (by HCl titration), orifice pressure drop for flow rate, static pressures at Ports 1-3, lime slurry flow rate, barometric pressure, wet bulb temperatures at Ports 1-3, and ambient temperature. Air in-leakage rate and flue gas molecular weight (from Orsat analyzer data) were conducted periodically. In addition to these measurements, analyses were conducted in the laboratory to determine the size distribution of the slaked $Ca(OH)_2$ particles in the slurry and the moisture content of the reacted products collected in the spray dryer and fabric filter collector hoppers.

SECTION 4

OVERVIEW OF SPRAYMOD COMPUTER MODEL

4.1 BRIEF DESCRIPTION OF THE SPRAYMOD COMPUTER MODEL

The SPRAYMOD computer program is a simulation program which mathematically models the removal of SO_2 in a spray dryer. The model developed by Research Triangle Institute (1) under contract to EPA is a simultaneous heat and mass transfer model which predicts the simultaneous evaporation of a sorbent (lime) droplet and absorption/reaction of SO_2 in the evaporating droplet. Further the model includes the dissolution kinetics of the $Ca(OH)_2$ particles within the droplet. A schematic flow chart of the computer program is given in Figure 2. Since the detailed description of SPRAYMOD has been reported elsewhere (1), it will not be discussed here except as needed for clarification of the input parameters to the model.

Analyses conducted in this report were conducted using the computer program, SPRAYMOD (1). Three minor changes were made in the program due to errors in the program reported by Damle (1). The following lines were added or modified:

```
2840  XS = XS/(1 + DX): XW = XW (1 + DX)

4065  XS = SI * (1-P1) * (1 - WO) / (1 - WI)

4780  XS = SI * (1 - EF) * (1-WO) / (1-WI)
```

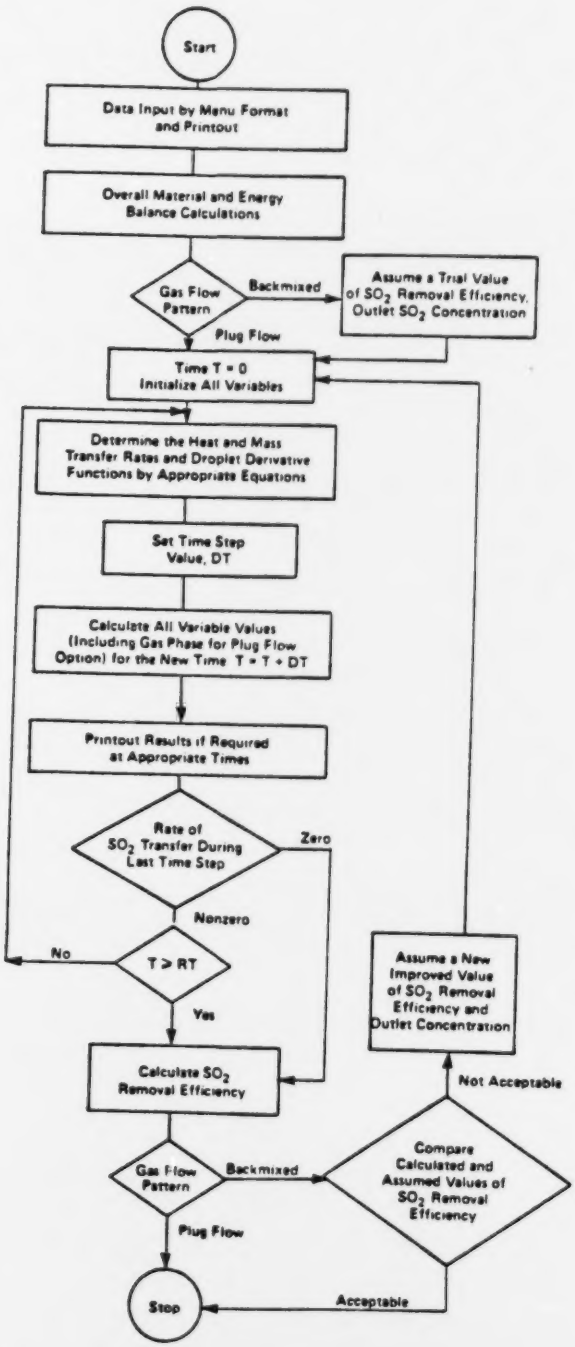
Start
Data Input by Menu Format and Printout
Overall Material and Energy Balance Calculations
Gas Flow Pattern
Backmixed
Assume a Trial Value of SO_2 Removal Efficiency, Outlet SO_2 Concentration
Plug Flow
Time T = 0 Initialize All Variables
Determine the Heat and Mass Transfer Rates and Droplet Derivative Functions by Appropriate Equations
Set Time Step Value, DT
Calculate All Variable Values (Including Gas Phase for Plug Flow Option) for the New Time T = T + DT
Printout Results if Required at Appropriate Times
Rate of SO_2 Transfer During Last Time Step
Zero
Nonzero
No
T > RT
Yes
Assume a New Improved Value of SO_2 Removal Efficiency and Outlet Concentration
Calculate SO_2 Removal Efficiency
Not Acceptable
Gas Flow Pattern
Backmixed
Compare Calculated and Assumed Values of SO_2 Removal Efficiency
Plug Flow
Stop
Acceptable

Figure 2. Flowchart for program SPRAYMOD (Damle, reference 1).

4.2 INPUT TO SPRAYMOD

4.2.1 Inlet Gas Conditions

The required gas conditions which are input to the model include the spray dryer inlet gas temperature (°C), the inlet water content of the flue gas (% by volume), the inlet SO_2 concentration (in ppm on a wet basis), and the flue gas molecular weight (on a dry basis).

4.2.2 Operating Conditions

The operating conditions include the approach to the adiabatic saturation temperature (°C) at the spray dryer outlet, the stoichiometric ratio of $Ca(OH)_2$ (moles of $Ca(OH)_2$/mole of inlet SO_2), mass fraction of reactive sorbent in fresh solids (1.0 if no recycle), recycle ratio (zero for no recycle), mass fraction of active sorbent in recycle (zero for no recycle), residence time (seconds) of the gas phase based on the volumetric flow rate at the outlet of the spray dryer, the type of mixing condition in the spray dryer (backmix versus plug flow), and an assumed spray dryer efficiency. This latter condition is only utilized in the backmix option as a starting point for the calculations.

4.2.3 Sorbent Conditions

Sorbent conditions required as input to the model include the inlet droplet diameter (μm), the inlet droplet temperature (°C), form of sorbent (slurry versus solution), sorbent mean particle diameter (μm), molecular weight of sorbent (74 g/mole for $Ca(OH)_2$), the density of solid sorbent (2.2 g/cm^3), critical moisture content (XC), equilibrium moisture content (XE), and the dry sorbent reaction rate coefficient (KR). The moisture contents are on a mass basis.

The inlet droplet diameter used in this study for the pilot plant data was calculated utilizing Equation 1 developed by Masters (2):

$$DVS = \frac{[1.4 \times 10^4 (M)^{0.24}]}{[(Nd)^{0.83} (nh)^{0.12}]} \quad (1)$$

where:

DVS = Sauter mean diameter (μm)
M = mass feed rate (kg/h)
N = atomizer wheel speed (rpm)
d = atomizer wheel diameter (m)
n = number of vanes
h = atomizer wheel vane height (m)

For the pilot plant data described here, M = 34-84 kg/h, N = 16,630-18,000 rpm, d = 0.15 m, n = 6, and h = 0.0066 m. The resulting range of calculated droplet diameters is 72-89 μm.

The sorbent particle diameter, based on measurement of the particle size distribution in the laboratory, was found to be 2.9-3.4 μm (volume mean diameter) with a geometric standard deviation of 1.5-1.8. An average value of 3.25 μm was used here. This compares with data reported by Stevens et al. (3) in which the range was reported to be 3.5-4.4 μm.

The equilibrium moisture content of the drying product is defined as the water content that would exist if the flue gas were at 100% saturation (100% relative humidity). This value was approximated by assuming that the moisture content of the product was linearly related to the relative humidity. Figure 3 shows a graph of water content of product versus stoichiometric ratio for pilot plant data collected in the UT system (Data Set 2). For the condition tested (8.9-10°C approach to saturation), the moisture content was approximately 1-11%, with an average value of approximately 3%. Previous test data on a full-scale spray dryer have shown moisture contents of 2-3% at the same approach to saturation (4). The relative humidity for these conditions was 40-50%; using 50% relative humidity and a 3% moisture content in the product, the equilibrium moisture content was estimated to be approximately 6% for the data evaluated in this study.

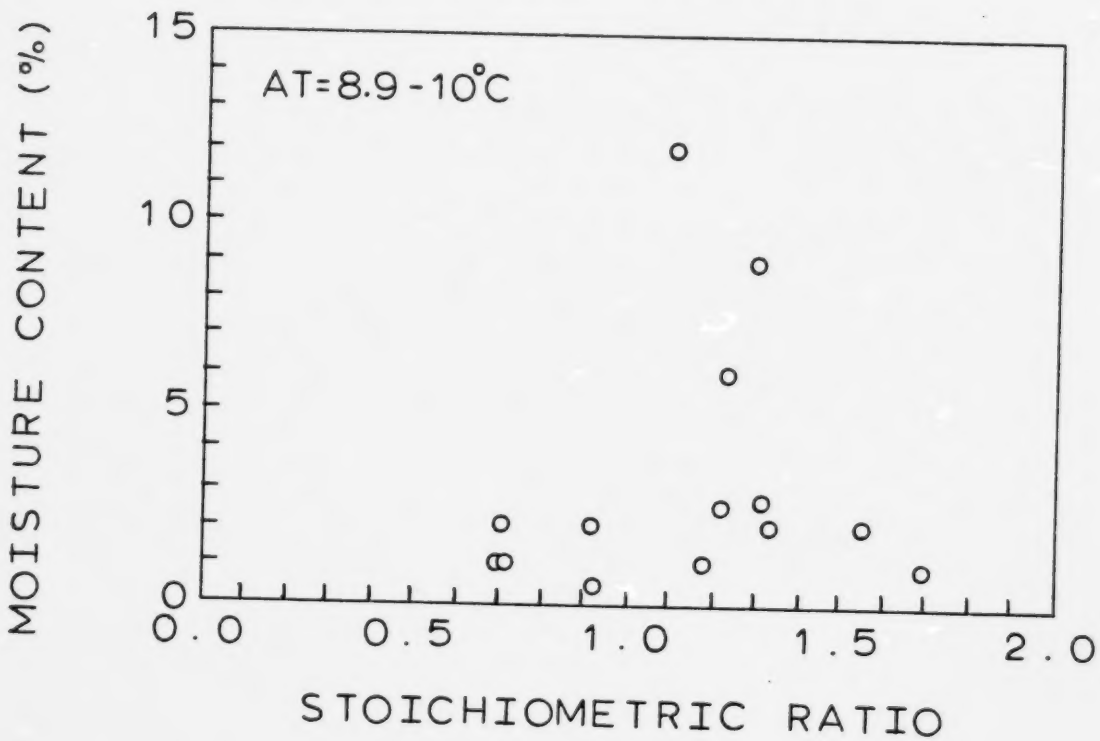

Figure 3. The moisture content of the product as a function of stoichiometric ratio for a $Ca(OH)_2$ slurry (Data Set2).

The critical moisture content of the product is defined as the moisture content of the droplet at which the solid's concentration begins to influence the drying rate. The condition in SPRAYMOD at which the model switches to a "dry particle stage" reaction, was chosen as 50% (1). Further, the dry sorbent reaction rate coefficient (KR) was initially assigned a value of zero. This value, as discussed by Damle (1), is a function of the particle moisture content and will be discussed further in this paper in light of the results from data analyses.

Table 1 summarizes the input conditions required to execute the computer simulation which include those described above as well as program parameters. Typical values are included.

SECTION 5

PRELIMINARY SENSITIVITY ANALYSES OF SPRAYMOD

Prior to conducting the above analyses, a partial sensitivity analysis was conducted of SPRAYMOD to aid in determining whether the backmix or plug flow model would be utilized in the data comparisons and to determine which operating conditions would result in significant changes in the predicted efficiency. A set of baseline conditions was chosen about which each input condition was varied. The baseline conditions are listed in Table 2. Figures 4 and 5 show a comparison of the predicted efficiencies for the model assuming the backmix and plug flow reaction schemes for reaction rate coefficients of 10^7 cm^3/mole-s and 0 cm^3/mole-s, respectively. The values indicate that the backmix and plug flow options show the efficiency to be relatively insensitive to most operating conditions when the reaction rate coefficient (KR) was 10^7 cm^3/mole-s. Further, the predicted efficiency values (for the spray dryer with lime only) were observed to be consistently higher than the values observed in the pilot plant tests to be analyzed for a value of KR of 10^7 cm^3/mole-s for both the backmix and plug flow options.

TABLE 1. INPUT TO SPRAYMOD

Input Data Set - PROGRAM SIMULATION

Inlet Gas Conditions -
- Inlet Gas Temperature (TI) - 160°C
- % Water in Inlet Gas (WI) - 6.5%
- Inlet SO_2 Concentration (SI) - 800 ppm
- Molecular Weight of Dry Inlet Gas (MG) - 28.9

Operating Conditions -
- Approach to Saturation (AT) - 15°C
- Stoichiometric Molar Ratio (SR) - 1
- Mass Fraction of Sorbent in Fresh Solids (MF) - 1
- Recycle Solids Ratio by Mass (RR) - 0
- Mass Fraction of Sorbent in Recycle (MR) - 0
- Residence Time of Gas Phase (RT) - 10 s
- Flow System in Spray Dryer - OP = 1 (Plug flow) - OP = 2 (Backmix)
- Assumed Spray Dryer Efficiency (P1) - 50%

Sorbent Conditions -
- Inlet Droplet Diameter (DO) - 50 μm
- Inlet Droplet Temperature (TW) - 60°C
- Form of Sorbent - Slurry (OS = 1)
- Sorbent Particle Diameter (DP) - 4 μm
- Molecular Weight of Sorbent (MS) - 74
- Density of Solid Sorbent (SG) - 2.2 g/cm^3
- Critical Moisture Content (XC) - 50% (Mass Basis)
- Equilibrium Moisture Content (XE) - 3% (Mass Basis)
- Dry Sorbent Reaction Rate Coefficient (KR) - 1E+07 cm^3/gmole-s

Program Parameters -
- Maximum Allowable Time Step (MT) - 0.1 s
- Time Between Printouts (PT) - 0.5 s
- Time Step Control Parameter (SC) - 0.01 s

TABLE 2. BASELINE CONDITIONS FOR SENSITIVITY ANALYSES

Parameter[a]	Baseline Value
TI (°C)	149
WI (%)	5
SI (ppm)	1100
MG	28.6
AT (°C)	11.1
SR	1.0
MF	1.0
RR	0
MR	0
RT (s)	17
OP	1 or 2
DO (μm)	80
TW (°C)	26.7
OS	1
DP (μm)	3.5
MS	74
SG (g/cm^3)	2.24
XC (%)	50
XE (%)	6
KR (cm^3/g mole-s)	0 or 1×10^7

[a]See Table 1 for definition of symbols

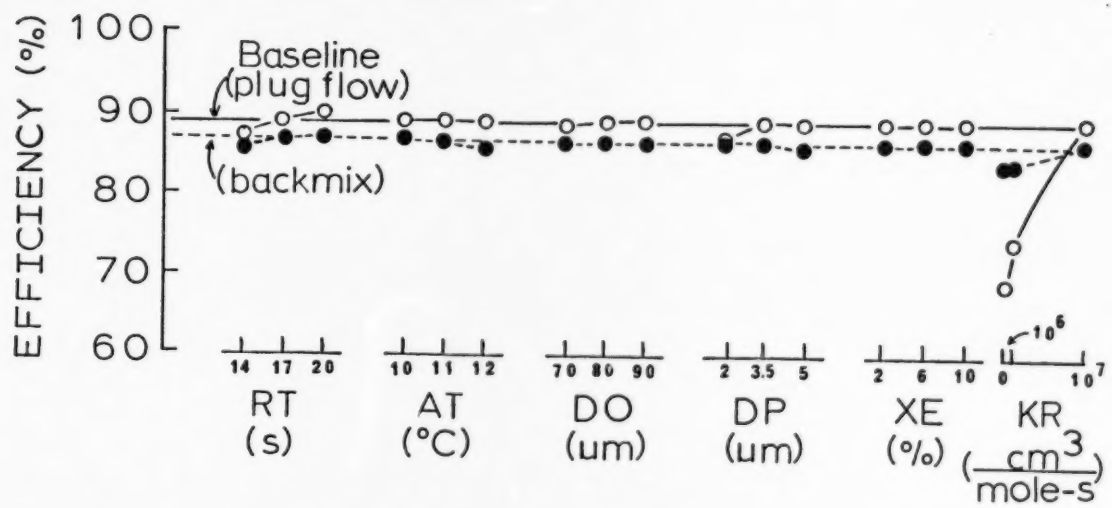

Figure 4. Comparison of the sensitivity of the complete (back) mix and plug flow models (KR = 10^7 cm^3/mole-s).

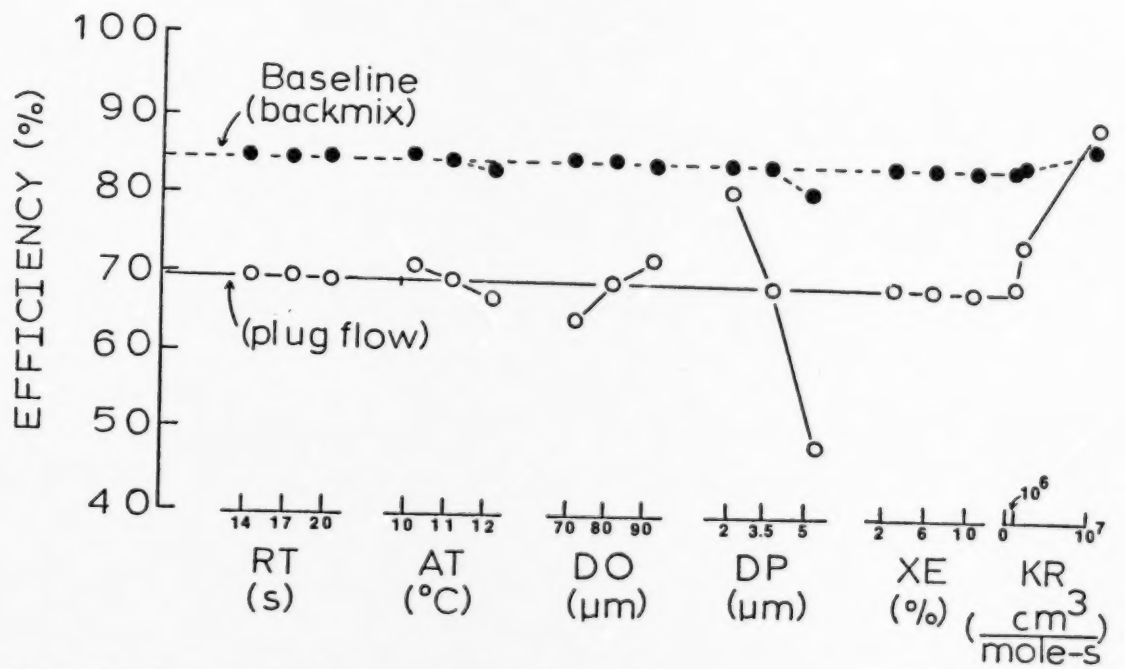

Figure 5. Comparison of the sensitivity of the complete (back) mix and plug flow models (KR = 0 cm^3/mole-s).

The plug flow option showed a significant dependence on the reaction rate coefficient, KR, as shown by a comparison of the baseline efficiency in Figures 4 and 5. It was also noted that, for the condition in which the reaction rate coefficient was 10^7 cm^3/mole-s (Figure 4), the plug flow model was relatively insensitive to other operating and gas characteristics such as residence time, approach to saturation, droplet diameter, and lime particle size since the utilization was relatively high (greater than 85%). However, when KR was set equal to zero (Figure 5), resulting in a significant reduction in efficiency (plug flow model only), the model became much more sensitive to the other variables.

A brief sensitivity analysis was conducted on the effect of KR on the efficiency versus stoichiometric ratio. Figure 6 shows a graph of efficiency versus stoichiometric ratio for KR ranging from 0-10^7 cm^3/mole-s for the baseline conditions in Table 2. Note that the reaction rate coefficient does not affect the efficiency significantly until KR exceeds a value of 10^5 cm^3/mole-s. Further, the effect of the choice of KR value is more pronounced at the higher SR values than at the lower SR values. This leads to the realization that the ability of the model to accurately predict the observed efficiency depends to a large extent on the user's choice of a reaction rate coefficient. As was emphasized by Damle (1), the reaction rate coefficient depends upon the diffusivity of SO_2 in the solid material, the particle size, and the moisture content of the droplet/particle. Since the lime particle size can be measured, the primary unknown factor affecting KR is the moisture content. At the present time, the value of KR has not been measured and included in the model. Davis and Keener (5) have measured the reaction rate coefficient, KR, of dry $Ca(OH)_2$ in a bench-scale reactor and obtained a value of approximately 25 cm^3/mole-s at a temperature of 140°F. However, it is expected that KR would be orders of magnitude higher at 1-10% moisture content. It is

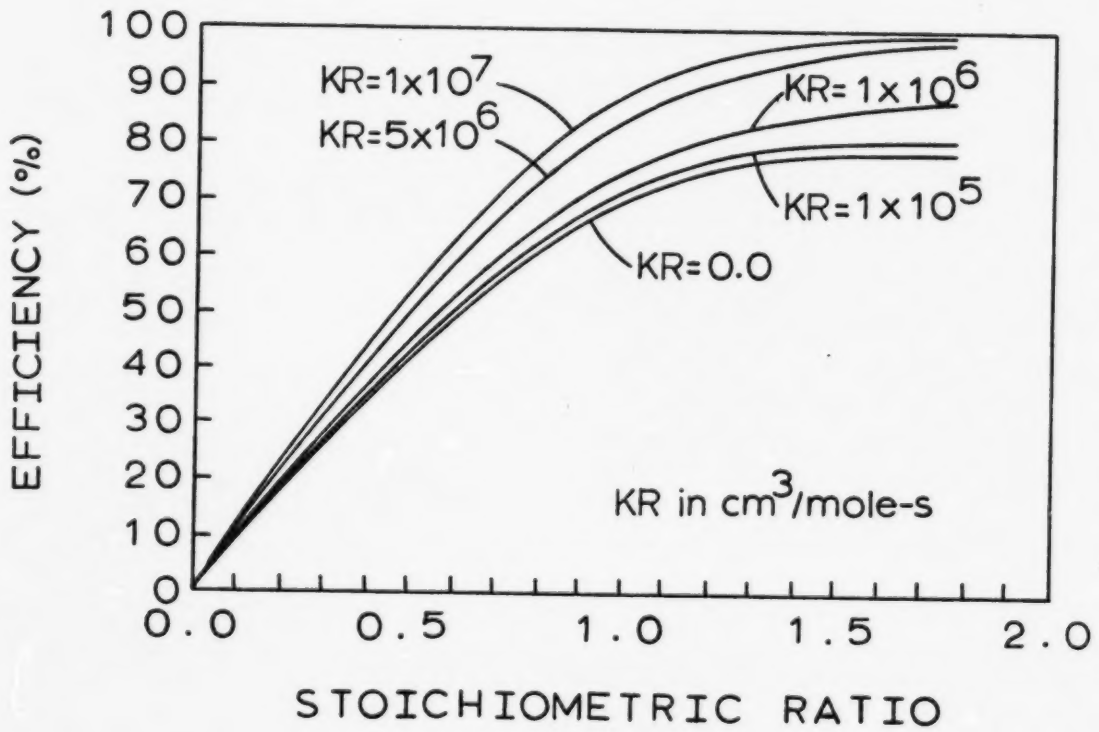

Figure 6. Effect of KR on the efficiency for the baseline condition (plug flow).

recommended that a value of KR = 0 be assumed until further information becomes available.

Based on the above observations from the sensitivity analyses and the reported and observed sensitivity of the measured efficiencies to lime particle size and approach to saturation, the analyses reported in this study were conducted with the plug flow model utilizing a KR value of zero.

SECTION 6

COMPARISON OF SPRAYMOD TO SPECIFIC DATA SETS

Analyses were conducted using the operating and gas conditions shown in Table 3. In total, 12 different data sets were utilized. Data analyses were conducted by comparing the measured efficiency versus stoichiometric ratio curve for each data set to the model predicted efficiency versus stoichiometric ratio curve for the data set. The data sets were collected from several research contracts. The quantity of data as well as the parameters vary considerably due to emphasis being placed on an intensive study of a relative small range of operating conditions in one case, while in another the emphasis was on studying a wide range of conditions.

While a detailed error analysis was not conducted during each of the tests from which the data sets were taken, a series of analyses were conducted to determine the error associated with measurement of the SO_2 removal efficiency and stoichiometric ratio. Based on the analyses conducted, the reported efficiency value based on the average inlet and outlet concentrations during each 1 hour test were within ± 4% of the extremes observed during the test. The stoichiometric ratio is a calculated value based on independent measurements of the slurry flow rate, slurry concentration, system flue gas flow rate, and the inlet SO_2 concentration. As a result, an analysis of errors of each of the independent measurements indicates that any single determination of the

TABLE 3. SUMMARY OF PILOT PLANT DATA SETS[a]

Parameter	1[b]	2[b]	3[b]	4[c]	5[b]	6[b]	7[b]	8[b]	9[b]	10[b]	11[c]	12[c]
TI (°C)	145	150	148	172	145	126	146	137	130	154	171	169
WI (%)	5.0	4.3	5.5	5.6	5.0	4.3	4.5	5.4	6.1	4.5	6.9	6.6
SI (ppm)	913	1103	1075	1012	1543	2332	2254	1979	1926	2095	1986	2893
MG	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4	29.4
AT (°C)	11.1	8.9-10.0	11.1	19.4	17.2	8.3	8.4	14.1	19.5	19.4	19.4	19.4
SR	----------		0.6	to		2.0	----------	----------				
MF	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
RR	0	0	0	0	0	0	0	0	0	0	0	0
MR	0	0	0	0	0	0	0	0	0	0	0	0
RT (sec)	15.2	16.6	19.5	17.5	16.1	16.5	16.4	15.1	15.0	15.1	16.4	17.6
OP	----------		plug flow (OP = 1)									
DO (μm)	82	80	79	77	75	79	80	83	77	80	78	79
TW (°C)	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8	37.8
OS	1	1	1	1	1	1	1	1	1	1	1	1
DP (μm)	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25	3.25
MS	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1	74.1
SG (g/cm^3)	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24	2.24
XC (%)	50	50	50	50	50	50	50	50	50	50	50	50
XE (%)	6	6	6	6	6	6	6	6	6	6	6	6
KR (cm^3/mole-s)	0	0	0	0	0	0	0	0	0	0	0	0

*Values reported are the average values for the data set.
[a] Parameter symbols are defined in Table 1.
[b] Utilized the shaker baghouse
[c] Utilized the pulse jet baghouse

stoichiometric ratio would be within ± 11% of the calculated value.

Table 4 summarizes each data set and identifies the figure in which the data are shown. A comparison of the data sets shown in Figures 8-15 shows that the model was capable of predicting the performance of the spray dryer under certain conditions such as Data Sets 2, 3, and 8. However, there was an observed tendency to under-predict the lower SO_2 concentration data and to over-predict the higher SO_2 concentration data as evidenced by Data set 4 and Data sets 11 and 12, respectively. It was generally observed that the predicted curves were consistently less sensitive to stoichiometric ratio (SR) than the observed data for SR greater than 1.0. This observation is seen particularly in Figures 7,10,11,12, and 15 where the data set efficiencies continue to increase with stoichiometric ratio and the model tends to predict only a small increase in efficiency above a stoichiometric ratio of approximately one. It was not immediately obvious from the figures whether there were other operating conditions which were influencing the ability of the model to over- or under- predict.

To investigate the ability of the model to predict at the various operating conditions, the ratio of model predicted efficiency to pilot data efficiency was calculated at a nominal stoichiometric ratio of one for the ranges of SO_2 concentrations, slurry concentrations, inlet temperatures, and approaches to saturation for the input data analyzed. This evaluation was conducted to determine if the model's tendency to over- or under-predict would be related to any one of these conditions as a single controlling condition, realizing that the SO_2 concentration, inlet temperature, and approach to saturation are independent conditions. The slurry concentration at a constant stoichiometric ratio is dependent on all three of these conditions in that an increase in SO_2 concentration, and/or approach to saturation, and/or a decrease in the inlet temperature result in an increase in the slurry concentration.

The following listing summarizes the range of operating conditions investigated and identifies the figures which illustrate the comparisons:

TABLE 4. SUMMARY OF DATA SETS AND FIGURES COMPARING MODEL'S PREDICTED SO_2 REMOVAL EFFICIENCY CURVE TO PILOT PLANT DATA

Data Set	Figure	Inlet SO_2 Concentration (ppm)	Inlet Temperature °C (°F)	Approach to Saturation °C (°F)
1	7	633-1163	145 (293)	11.1 (20)
2	8	936-1222	150 (302)	8.9-10 (16-18)
3	8	940-1205	148 (298)	11 (20)
4	9	941-1074	172 (342)	19.4 (35)
5	10	1504-1620	145 (293)	17.2 (31)
6	11	2216-2416	126 (259)	8.3 (15)
7	12	2044-2353	146 (295)	8.4 (15)
8	13	1903-2149	137 (279)	14.1 (25)
9	14	1723-2184	130 (266)	19.5 (35)
10	14	2052-2146	154 (309)	19.4 (35)
11	15	1890-2057	171 (340)	19.4 (35)
12	15	2633-3178	169 (336)	19.4 (35)

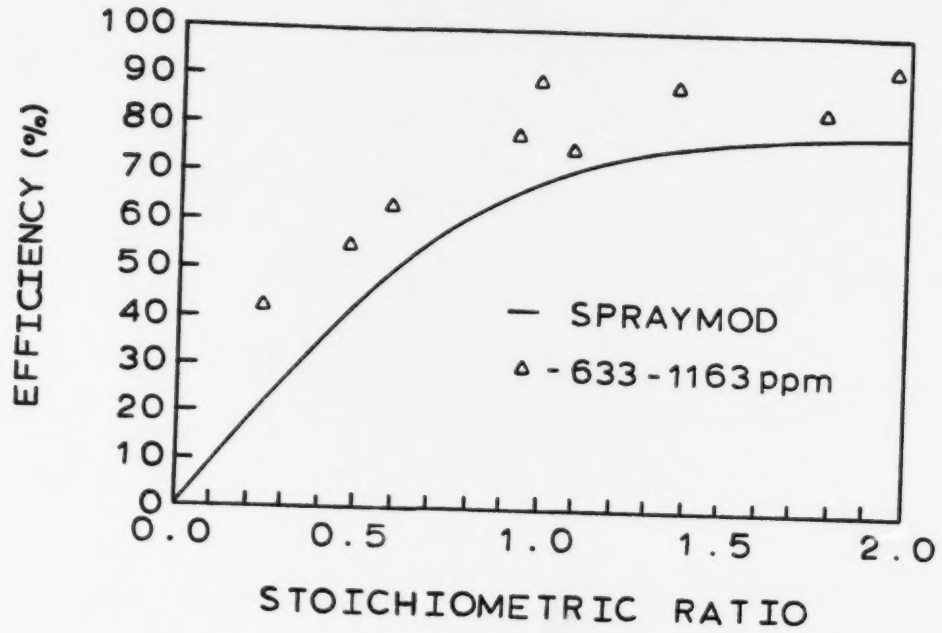

Figure 7. Comparison of SPRAYMOD predicted efficiencies to measured efficiencies for 633-1163 ppm of SO_2 at a 11.1°C (20°F) approach to saturation (Data Set 1).

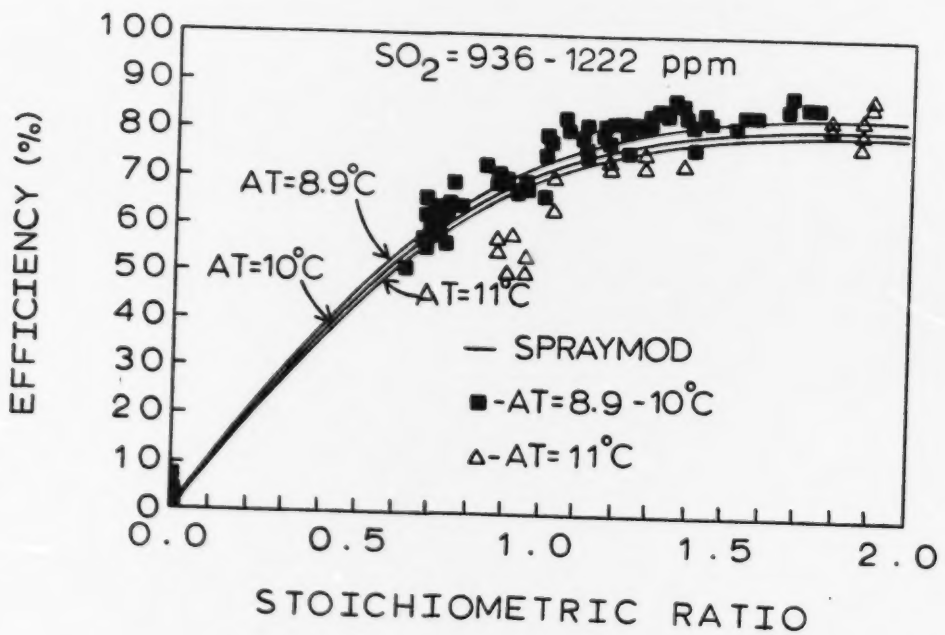

Figure 8. Comparison of SPRAYMOD predicted efficiencies to measured efficiencies for 936-1222 ppm of SO_2 (Data Sets 2 and 3).

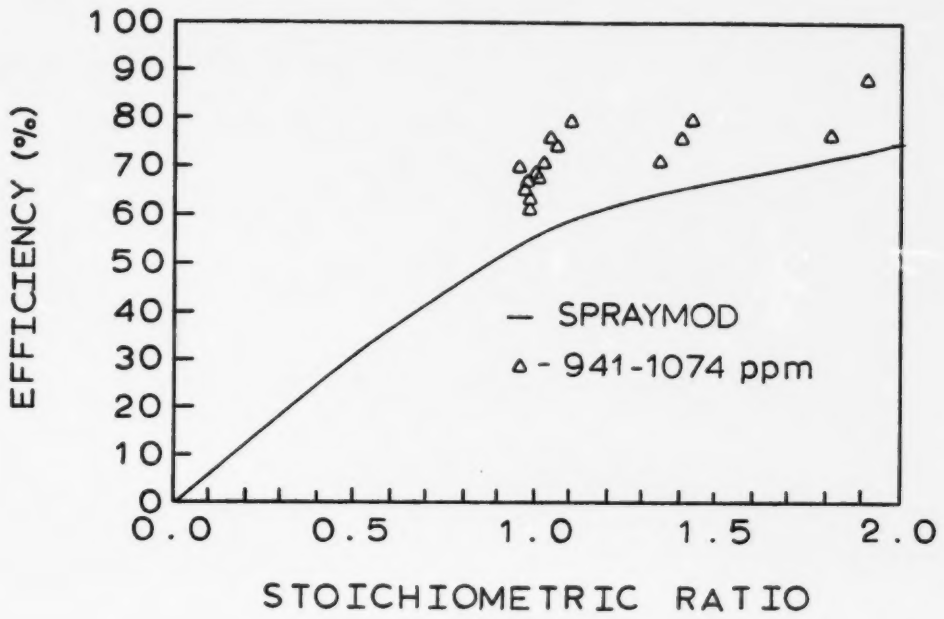

Figure 9. Comparison of SPRAYMOD predicted efficiencies to measured efficiencies for 941-1074 ppm of SO_2 at a 19.4°C (35°F) approach to saturation (Data Set 4).

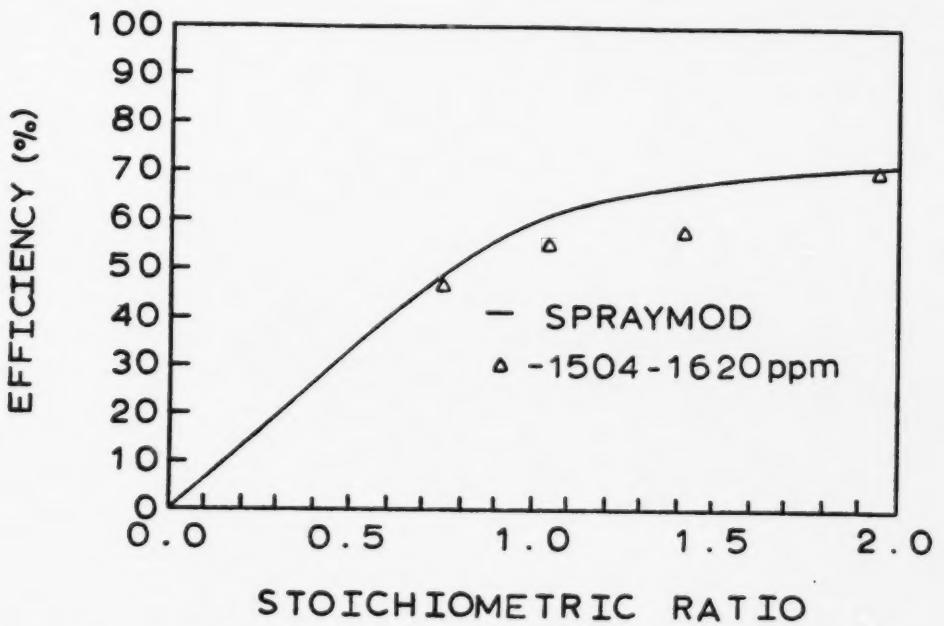

Figure 10. Comparison of SPRAYMOD predicted efficiencies to measured efficiencies for 1504-1620 ppm of SO_2 at a 17.2°C (31°F) approach to saturation (Data Set 5).

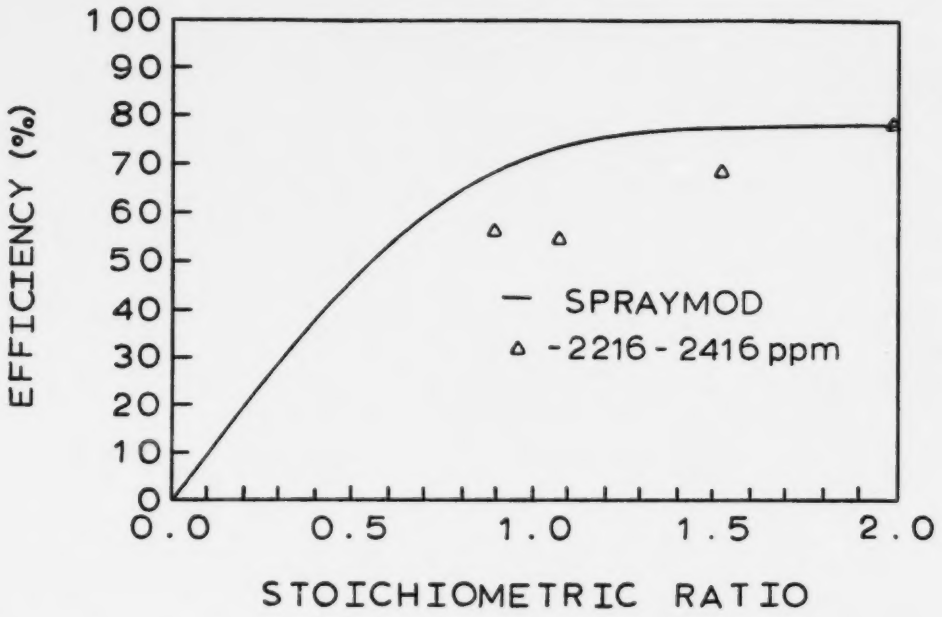

Figure 11. Comparison of SPRAYMOD predicted efficiencies to measured efficiencies for 2216-2416 ppm of SO_2 at a 8.33°C (15°F) approach to saturation (Data Set 6).

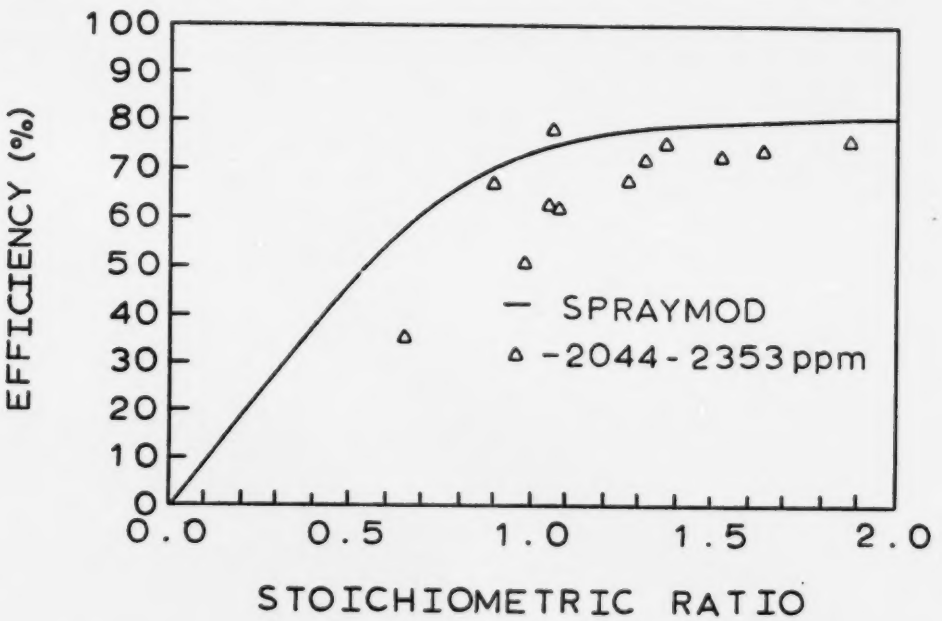

Figure 12. Comparison of SPRAYMOD predicted efficiencies to measured efficiencies for 2044-2353 ppm of SO_2 at a 8.38°C (15°F) approach to saturation (Data Set 7).

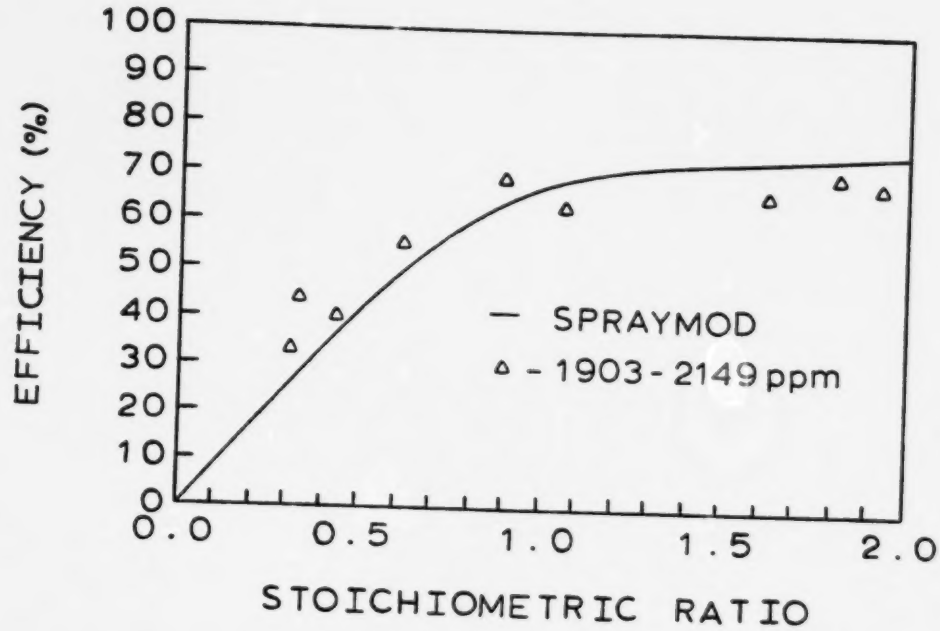

Figure 13. Comparison of SPRAYMOD predicted efficiencies to measured efficiencies for 1903-2149 ppm of SO_2 at a 14.1°C (25°F) approach to saturation (Data Set 8).

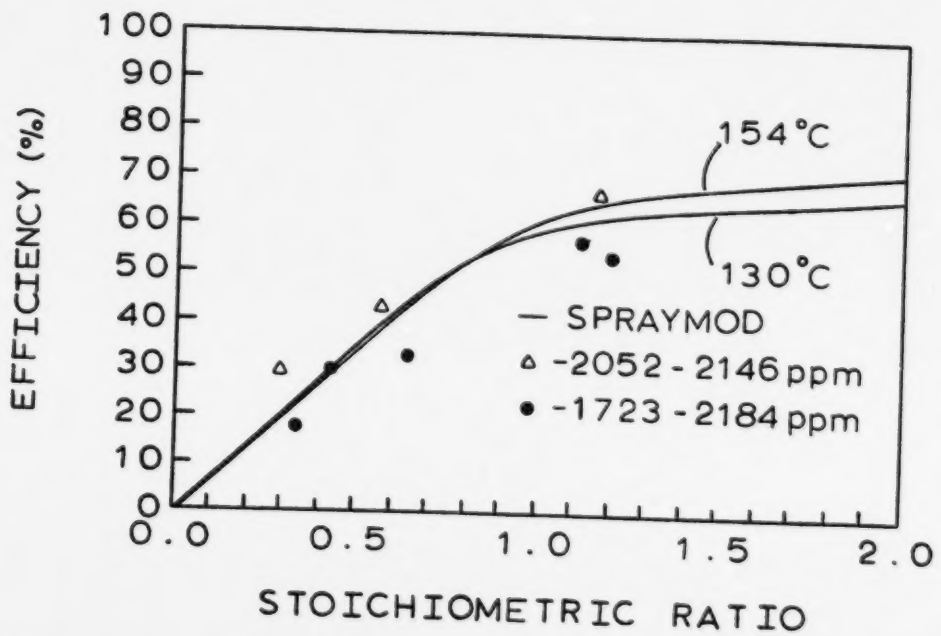

Figure 14. Comparison of SPRAYMOD predicted efficiencies to measured efficiencies for high SO_2 concentrations (1723-2184 ppm) at a 19°C (35°F) approach to saturation with 130°C (266°F) and 154°C (309°F) inlet temperatures (Data Sets 9 and 10).

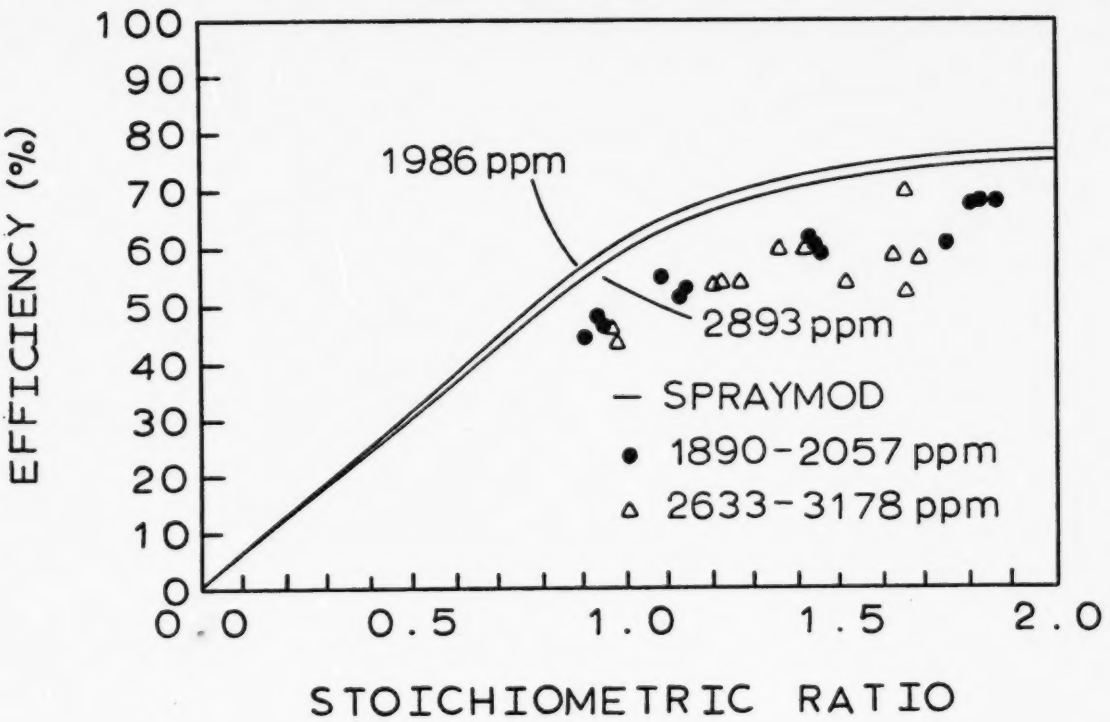

Figure 15. Comparison of SPRAYMOD predicted efficiencies to measured efficiencies for high SO_2 concentrations (1890-3178 ppm) at 19.4°C (35°F) approach to saturation (Data Sets 11 and 12).

Figure 16: SO_2 Concentration (974-3056 ppm)

Figure 17: Slurry Concentration (53-167 g/l $Ca(OH)_2$)

Figure 18: Inlet Temperature (127-172°C)

Figure 19: Approach to Saturation (8.2-19.5°C)

The data points used in each data set were in the stoichiometric ratio range of 0.9-1.1 with the exception of two points at stoichiometric ratios of 1.12 and 1.17. The slurry concentrations were normalized to a stoichiometric ratio of one and the operating conditions were averaged for each data set.

The comparisons of efficiency ratio (model/data) indicated a trend in the model of under-predicting at low slurry concentrations and low SO_2 concentrations while the model trend was over-predicting at the higher slurry concentrations and SO_2 concentrations as seen in Figures 16 and 17. The comparisons of efficiency ratios with predicted values for inlet temperatures and approaches to saturation are given in Figures 18 and 19 with no trends being observed. Since slurry concentration would increase at a given stoichiometric ratio as the SO_2 concentration increased, then the data in both Figures 16 and 17 are related to each other in terms of slurry concentration effects. If only a trend was observed for the SO_2 concentration comparison, it would indicate that the reaction of the SO_2 in the slurry droplet was limited by mass transfer. However, there was a distinct trend in both the slurry concentration and SO_2 comparisons; this is a strong indication that the deficiency of the model is in the area of $Ca(OH)_2$ dissolution and diffusion as affected by changes in slurry concentration.

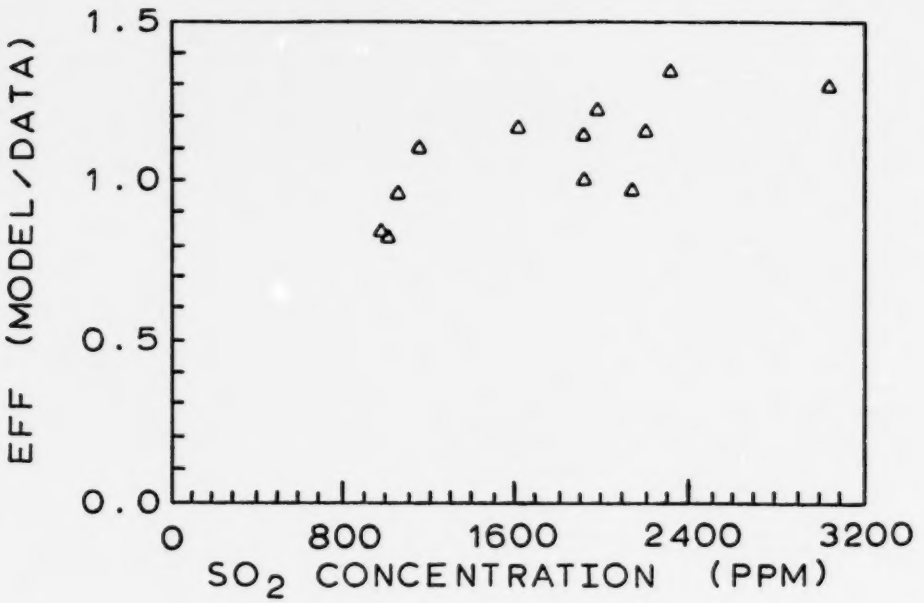

Figure 16. Comparison of efficiency ratio (model/data) to SO_2 concentration (ppm) at a stoichiometric ratio of one.

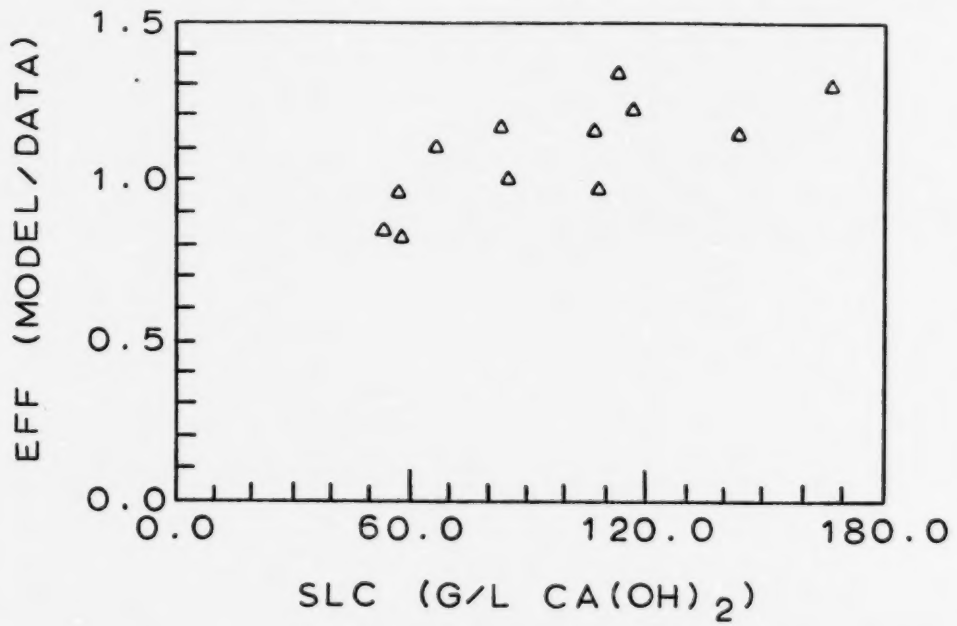

Figure 17. Comparison of efficiency ratio (model/data) to slurry concentration (g/l $Ca(OH)_2$) at a stoichiometric ratio of one.

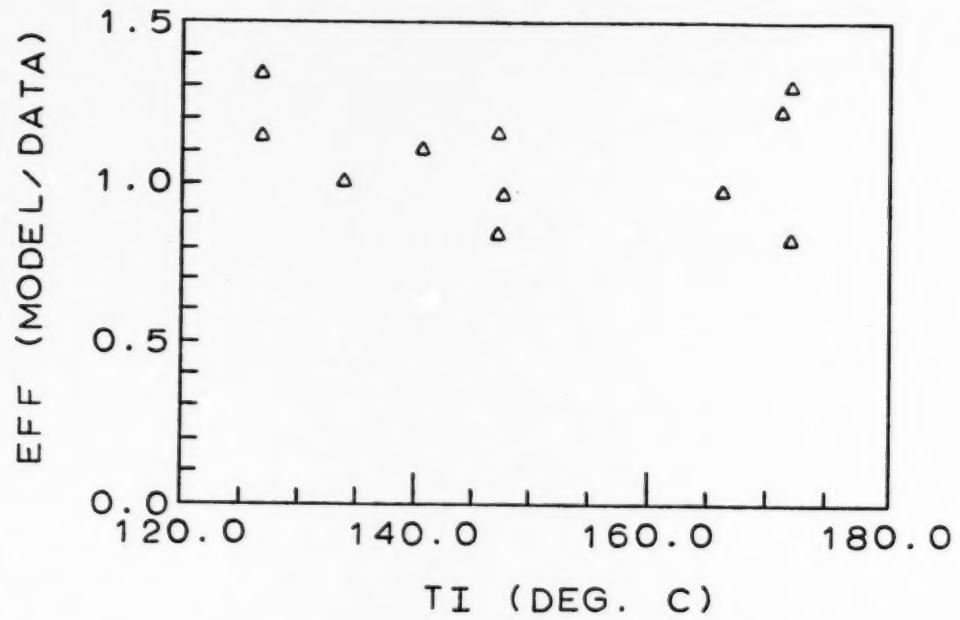

Figure 18. Comparison of efficiency ratio (model/data) to inlet temperature (°C) at a stoichiometric ratio of one.

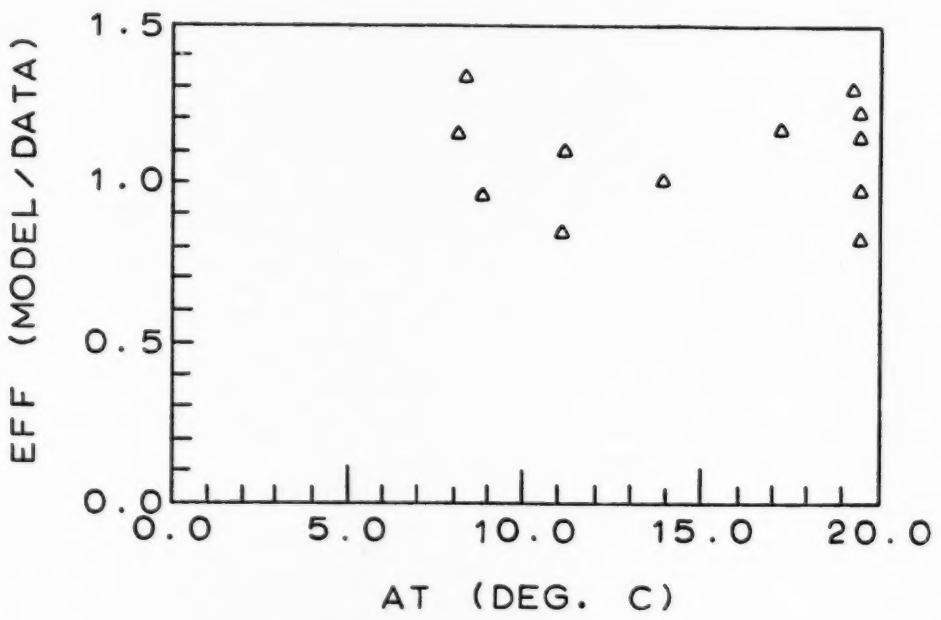

Figure 19. Comparison of efficiency ratio (model/data) to approach to saturation (°C) at a stoichiometric ratio of one.

SECTION 7

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4. Kelly, M.E. and M.A. Palazolo. Status of Dry SO_2 Control Systems: Fall 1982. EPA-600/7-83-041 (NTIS No. PB83-247585), August 1983, pp. 105-106.

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Appendix A

MULTIPLICATIVE CONVERSION FACTORS TO OBTAIN SI UNITS

MULTIPLICATIVE CONVERSION FACTORS TO OBTAIN SI UNITS

TO OBTAIN	MULTIPLY	BY
	MASS	
Kilograms (kg)	Grams (g)	0.001
	LENGTH	
Meters (m)	Inches (in.)	0.0254
Meters (m)	Feet (ft)	0.3048
	VOLUMETRIC FLOW RATE	
Cubic meters/sec (m^3/s)	Cubic feet/min. ($ft^3/min.$)	4.72×10^{-4}
Cubic meters/sec (m^3/s)	Gallons/min. (gpm)	6.308×10^{-5}

Appendix B

SPRAY DRYER PILOT PLANT SO_2 REMOVAL EFFICIENCY DATA AND OPERATING PARAMETERS

LIST OF ABBREVIATIONS

ABBREVIATIONS

ACFM3	--	Actual cubic feet per minute of gas flow measured at Port 3 (after the baghouse)
CS1	--	SO_2 concentration at Port 1 corrected for air leakage into pilot spray dryer system (ppm)
DATA EFF	--	SO_2 removal efficiencies measured across pilot spray dryer (%)
DT	--	Approach to saturation (°F)
DVS	--	Calculated slurry droplet diameter using equation developed by Masters (2), (μm)
F1	--	Fractional moisture content in flue gas at Port 1
GPM	--	Slurry feed rate to pilot spray dryer (gpm)
ID	--	Data identification number
MODEL EFF	--	SO_2 removal efficiency across pilot spray dryer predicted by SPRAYMOD
SC,SCFM1C	--	Standard cubic feet per minute at Port 1 corrected for air leakage into pilot spray dryer system
SLC	--	Slurry concentration (lb/gal CaO)
SPREFF	--	SO_2 removal efficiency across pilot spray dryer for pilot data (%)
SR	--	Stoichiometric molar ratio
T2	--	Temperature of flue gas at Port 2 (°F)
TEC,TEMP1C	--	Temperature of flue gas at Port 1 corrected for air leakage into pilot spray dryer system (°F)

DATA SET 1

ID	T2	SLC	GPM	ACFM3	SCFM1C	TEMP1C
10188201	136	0.000	.21	891	735	313
10118202	134	0.127	0.226	880	738	306
10198203	134	0.262	0.21	881	737	306
10118204	133	0.450	0.23	886	740	307
10118205	133	0.700	0.269	889	740	303
10118206	133	0.820	0.26	898	736	303
10198204	134	0.500	0.22	884	736	306
07128202	137	0.367	0.262	887	731	279
07128201	137	0.840	0.26	885	731	279
07098205	134	0.375	0.288	885	747	276
07098204	134	0.189	0.24	881	749	276
07098203	133	0.694	0.245	879	748	274

ID	CS1	SPREFF	SR	DVS	F1	DT
10188201	1027	5.3	0.000	77.7	0.052	20
10118202	1163	41.7	0.230	79.3	0.048	20
10198203	1091	54.9	0.470	78.2	0.048	20
10118204	1037	77.3	0.927	80.2	0.052	20
10118205	979	83.5	1.780	83.7	0.054	20
10118206	1013	92.8	1.970	83.2	0.053	20
10198204	1044	88.9	0.985	79.4	0.047	20
07128202	840	74.6	1.080	82.6	0.050	20
07128201	811	80.3	2.520	83.2	0.050	20
07098205	725	88.4	1.370	84.5	0.051	20
07098204	710	62.8	0.586	80.6	0.051	20
07098203	633	93.3	2.470	81.8	0.049	20

DATA SET 2

ID	T2	SLC	GPM	ACFM3	SCFM1C	TEMP1C
83021702	129	0	.16	813	673	305
83021703	129	0	.15	818	671	303
83021401	130	.49	.191	758	619	313
83021402	130	.49	.247	733	603	309
83021403	129	.49	.182	710	584	307
83021701	129	0	.19	814	675	295
83022101	129	.59	.271	806	690	302
83022102	129	.59	.235	806	691	300
83022103	129	.59	.242	806	691	300
83022104	130	.59	.227	806	691	299
83022105	129	.59	.247	806	691	298
83022203	130	.6	.24	804	676	308
83022204	130	.6	.26	800	677	312
83022205	130	.6	.25	800	676	318
83022301	129	0	.196	817	672	299
83022302	128	0	.227	817	673	296
83022303	128	0	.182	817	673	293
83022401	133	.6	.21	819	664	295
83022402	132	.6	.26	821	660	310
83022403	133	.6	.246	820	662	303
83022404	133	.6	.24	819	664	298
83022405	133	.6	.2	820	664	293
83022406	133	.6	.2	820	664	295
83022501	129	.6	.237	811	675	310
83022502	129	.6	.237	811	675	312
83022503	128	.6	.251	812	673	317
83022801	127	.6	.26	812	683	306
83022802	127	.6	.25	812	683	306
83022803	127	.6	.24	812	684	304
83022804	127	.6	.224	812	684	305
83020701	130	.8	.24	815	681	301
83020107	127	0	.24	820	711	309
83020106	127	0	.24	822	710	311
83020105	127	0	.23	822	710	311
83020104	127	0	.24	832	718	311
83020103	127	0	.24	803	693	309
83020102	127	0	.24	804	692	308
83020101	130	0	.21	806	692	304
83020301	130	.59	.24	807	684	305
83020302	129	.59	.21	816	691	303
83020303	130	.59	.21	764	648	302
83020304	129	.59	.23	816	690	305
83020305	129	.59	.23	806	681	305
83020401	131	.69	.25	842	698	301
83020402	131	.69	.22	817	683	300
83020403	131	.69	.213	773	649	300
83020404	130	.69	.218	837	698	305
83020405	130	.69	.227	806	672	304
83020702	130	.8	.24	785	654	300
83020703	130	.8	.242	818	678	301

DATA SET 2 (Continued)

ID	T2	SLC	GPM	ACFM3	SCFM1C	TEMP1C
83020704	130	.8	.212	788	651	300
83020706	130	.52	.232	841	695	300
83020707	129	.52	.236	798	662	297
83020708	129	.52	.2	809	669	297
83020709	129	.52	.215	776	644	296
83040401	128	.4	.228	823	678	296
83040402	128	.4	.218	823	678	294
83040403	128	.4	.225	823	678	294
83040404	127	.43	.222	822	678	295
83040405	128	.43	.203	822	678	296
83040601	132	.317	.25	825	671	311
83040602	133	.317	.226	824	673	307
83040603	132	.314	.237	824	672	308
83040604	132	.314	.229	814	665	304
83040605	132	.314	.205	804	657	302
83041101	129	.43	.238	839	680	300
83041102	128	.43	.237	825	681	305
83041103	128	.43	.236	823	682	304
83041104	128	.44	.227	823	682	303
83041105	128	.44	.264	803	666	299
83041106	128	.44	.266	793	658	295
83041201	127	.318	.249	822	684	305
83041202	127	.318	.22	812	677	300
83041203	127	.318	.24	812	675	308
83041204	127	.33	.254	801	667	308
83041205	127	.33	.248	792	660	299
83041206	127	.33	.221	802	668	300
83050307	131	.368	.212	810	652	293
83050306	131	.368	.213	821	660	293
83050305	131	.363	.205	822	659	298
83050304	131	.363	.207	821	661	290
83050303	131	.363	.223	822	660	292
83050302	131	.363	.223	822	661	288
83050301	131	.363	.225	825	660	287

DATA SET 2 (Continued)

ID	CSI	SPREFF	SR	DVS	F1	DT
83021702	1058	0	0	72.9	.038	19
83021703	1100	3.5	0	71.7	.039	19
83021401	983	82.3	1.06	76.8	.045	19
83021402	980	75.8	1.41	81.7	.047	19
83021403	949	78.6	1.11	75.9	.047	18
83021701	1104	-2.2	0	75.9	.041	19
83022101	1207	84.2	1.32	83.7	.047	18
83022102	1140	81.3	1.21	80.9	.048	18
83022103	1168	80.3	1.22	81.5	.048	18
83022104	1192	81	1.12	80.2	.048	19
83022105	1126	82.5	1.29	81.9	.048	18
83022203	1143	81.4	1.28	81.3	.036	18
83022204	1149	85.4	1.38	82.9	.035	18
83022205	1124	86.2	1.36	82.1	.033	18
83022301	1100	.9	0	76.5	.044	18
83022302	1040	1.7	0	79.2	.045	17
83022303	1020	3.8	0	75.1	.046	17
83022401	1117	78.8	1.17	78.7	.052	18
83022402	1052	83.4	1.55	82.9	.047	18
83022403	1198	80.2	1.28	81.8	.05	19
83022404	1212	75.7	1.23	81.3	.051	18
83022405	1222	77.7	1.02	77.8	.053	18
83022406	1172	79.8	1.06	77.8	.052	18
83022501	1133	82.1	1.28	81.1	.04	18
83022502	1127	81.5	1.29	81.1	.039	18
83022503	1158	82.9	1.33	82.2	.037	17
83022801	1133	82.2	1.39	82.9	.044	18
83022802	1044	82.4	1.45	82.1	.044	18
83022803	1170	81	1.24	81.3	.045	18
83022804	1143	80.8	1.18	80	.045	18
83020701	1164	87.8	1.67	81.6	.053	18
83020107	1074	.6	0	80.3	.03	18
83020106	1089	2.3	0	80.3	.029	18
83020105	1112	3.8	0	79.5	.029	18
83020104	1144	2.1	0	80.3	.029	18
83020103	1160	7.1	0	80.3	.03	18
83020102	1172	-.9	0	80.3	.03	18
83020101	1169	9.3	0	77.8	.032	21
83020301	1018	81.2	1.4	81.3	.048	18
83020302	1005	80.1	1.23	78.7	.039	17
83020303	1181	75	1.12	78.7	.039	18
83020304	1159	79.2	1.17	80.5	.038	17
83020305	1153	81.3	1.19	80.5	.038	17
83020401	936	79.8	1.82	82.3	.056	18
83020402	1053	83.2	1.45	79.8	.056	18
83020403	1023	81.3	1.52	79.2	.056	18
83020404	1031	83.4	1.44	79.6	.054	17
83020405	1016	83	1.58	80.4	.055	17
83020702	1160	85.5	1.74	81.6	.053	18
83020703	1136	85.5	1.73	81.8	.053	18

DATA SET 2 (Continued)

ID	CSI	SPREFF	SR	DVS	FI	DT
83020704	1079	84.4	1.66	79.2	.053	18
83020706	1074	79.4	1.11	80.5	.053	18
83020707	1086	77.6	1.18	80.9	.054	17
83020708	1063	74.9	1.01	77.7	.054	17
83020709	1067	75.4	1.12	79.1	.055	17
83040401	1056	69.9	.88	80	.034	18
83040402	979	69.9	.9	79.1	.035	18
83040403	947	67.6	.96	79.7	.035	18
83040404	1010	68.7	.96	79.5	.035	17
83040405	875	77.2	1.01	77.8	.034	18
83040601	1091	63.7	.75	81.7	.036	18
83040602	1075	65.3	.68	79.7	.037	19
83040603	998	68	.76	80.6	.037	18
83040604	1068	58.2	.7	79.9	.038	18
83040605	1007	56.9	.67	77.8	.039	18
83041101	1023	78.5	1.01	80.9	.04	18
83041102	1164	70.5	.89	80.8	.041	18
83041103	1155	69.8	.89	80.7	.042	18
83041104	1199	72.5	.84	80	.042	18
83041105	1280	66.6	.94	82.9	.043	18
83041106	1220	66.4	1	83.1	.045	18
83041201	1168	54.8	.68	81.6	.038	18
83041202	1131	50.6	.63	79.2	.039	18
83041203	1082	61.1	.72	80.9	.037	18
83041204	1194	57.2	.72	82	.037	18
83041205	1171	55.8	.73	81.5	.04	18
83041206	1083	56.9	.69	79.3	.039	18
83050307	1139	61.1	.72	78.6	.047	18
83050306	1132	63.3	.72	78.7	.047	18
83050305	1150	61.8	.68	77.9	.046	18
83050304	1115	57.7	.7	78.1	.048	18
83050303	1141	60.8	.74	79.5	.047	18
83050302	1173	60.5	.72	79.5	.049	18
83050301	1092	64.2	.78	79.7	.049	18

DATA SET 3

ID	T2	SLC	GPM	ACFM	SC	TEC
84012701	136	.64	.235	688	558	292
84012703	133.5	.46	.234	689	565	292
84012704	134.5	.46	.214	684	561	294
83121402	135	.5	.22	657	547	296
83121501	136	.689	.24	681	549	308
83121502	136	.682	.24	675	547	306
83121503	135.4	.68	.24	663	544	304
83121601	136	.701	.26	705	605	296
83121602	136	.701	.26	705	604	296
84020201	139.5	.537	.154	669	548	286
84020202	138	.537	.149	664	546	294
84020203	138	.537	.155	660	542	294
84020204	138	.537	.159	691	567	293
84020304	136	.554	.181	682	559	280
84021504	134	.698	.243	697	567	302
84021505	134	.698	.238	686	565	289
84030501	140	.69	.265	714	562	322
84031301	138	.698	.235	719	581	308
84020204	138	.537	.159	691	567	293
84020304	136	.554	.181	682	559	280
84021504	134	.698	.243	697	567	302
84021505	134	.698	.238	686	565	289
84030501	140	.69	.265	714	562	322
84031301	138	.698	.235	719	581	308

DATA SET 3 (Continued)

ID	CSI	SPREFF	SR	DVS	FI	DT
84012701	995	79.5	1.87	81	.056	20
84012703	941	72.2	1.39	80.6	.049	19
84012704	947	72	1.28	78.9	.052	19.5
83121402	1169	71.8	1.19	79.5	.056	19
83121501	1117	76.5	1.86	81.5	.051	20
83121502	1017	75.6	2.03	81.4	.056	20
83121503	1015	78.8	2.04	81.4	.056	19.4
83121601	976	81.1	2.13	83	.053	20
83121602	940	77.5	2.21	83	.053	20
84020201	1082	53	.96	73	.065	20.5
84020202	1150	57	.88	72.4	.062	20
84020203	1154	57.5	.92	73.1	.062	20
84020204	1134		.91	73.6	.062	20
84020304	1205	69.5	1.03	75.9	.06	20
84021504	961		2.14	81.7	.045	20
84021505	1085		1.87	81.3	.049	20
84030501	1180	85.8	1.9	83.4	.054	20
84031301	1089	82.5	1.79	81.1	.056	20
84020204	1134		.91	73.6	.062	20
84020304	1205	69.5	1.03	75.9	.06	20
84021504	961		2.14	81.7	.045	20
84021505	1085		1.87	81.3	.049	20
84030501	1180	85.8	1.9	83.4	.054	20
84031301	1089	82.5	1.79	81.1	.056	20

DATA SET 4

ID	T2	SLC	GPM	ACFM3	SC	TEC
84121102	158	.71	.194	736	606	340
84121303	157	.45	.189	743	604	342
84121304	157	.45	.19	737	604	343
84121305	157	.45	.189	729	598	342
84121302	157.5	.45	.193	746	604	342
84121307	157	.45	.194	730	598	342
84121308	157	.45	.194	730	598	342
84121401	154.5	.45	.19	732	602	342
84121402	155	.45	.19	729	599	342
84121403	155.5	.45	.188	731	603	342
84121404	156	.45	.189	731	604	342
84121405	156	.45	.189	729	604	342
84121406	156	.45	.189	730	605	342
84121407	156	.46	.191	728	604	342
84121408	155.5	.46	.194	729	604	342
84121701	156.5	0	.195	752	596	342
84121702	157	0	.195	745	593	342
84121703	156.5	0	.197	745	595	343
84121704	156.5	0	.19	747	596	342
84121705	157	0	.191	742	593	342
84121706	157	0	.192	738	590	342
84121707	156	0	.192	741	593	342
84121708	156	0	.192	738	590	342
85011401	157.5	.92	.195	752	591	341
85011402	158	.92	.194	749	591	340
85011501	157.5	.9	.196	774	631	341
85011502	157.5	.9	.194	775	633	340
85011503	157.5	.92	.192	769	630	340
85011504	157	.92	.19	765	626	340
85011702	157	.55	.192	846	679	340
85011703	156.5	.55	.192	838	676	340
85011704	156.5	.55	.193	832	673	339
85011705	157	.55	.192	825	668	341
85011706	156	.55	.194	824	667	340
85011707	156	.55	.194	832	673	341
85011708	156	.55	.194	825	669	340
85011709	156	.55	.193	823	667	340
85011803	157.5	.71	.193	825	665	340
85011801	156.5	.71	.192	821	665	339
85011802	157	.71	.192	828	668	341
85011804	157	.71	.192	829	668	340
85021301	156	.63	.192	775	631	339

DATA SET 4 (Continued)

ID	CS1	SPREFF	SR	DVS	F1	DT
84121102	1036		1.51	77.4	.059	35
84121303	1016		.95	76.6	.055	35
84121304	1005		.97	76.7	.057	35
84121305	1016	69.5	.96	76.6	.057	35
84121302	1003	62.4	.99	76.9	.055	35.5
84121307	1015	61	.99	77	.055	35
84121308	1042		.96	77	.055	35
84121401	1019		.96	76.7	.049	34.5
84121402	982	67.5	1	76.7	.05	35
84121403	988		.98	76.5	.05	34.5
84121404	987	64.6	.98	76.6	.052	35
84121405	1004		.97	76.6	.052	35
84121406	979	66.8	.99	76.6	.051	35
84121407	1027		.98	76.8	.052	35
84121408	1013	68.2	1	77.1	.052	34.5
84121701	1042	-.7	0	76.4	.061	34.5
84121702	1023		0	76.4	.061	35
84121703	1040	.7	0	76.6	.059	34.5
84121704	1013		0	75.9	.059	34.5
84121705	974	-.3	0	76	.057	36
84121706	988		0	76.1	.057	36
84121707	968	1.7	0	76.1	.057	35
84121708	1013	0	0	76.1	.057	35
85011401	999	86.9	2.09	77.8	.082	34
85011402	1005		2.07	77.7	.082	34
85011501	1063	76.8	1.81	77.9	.056	35
85011502	1070		1.78	77.7	.056	35
85011503	1014	88	1.91	77.5	.056	35
85011504	941		2.04	77.3	.056	34.5
85011702	976	79.7	1.1	77	.054	35
85011703	984		1.09	77	.054	34.5
85011704	1042	76.4	1.04	77.1	.055	34.5
85011705	1030		1.06	77	.054	35
85011706	1022		1.08	77.2	.05	35.5
85011707	1031	74.1	1.06	77.2	.05	35.5
85011708	1074	70.1	1.02	77.2	.05	35.5
85011709	1067		1.03	77.1	.05	35.5
85011803	990	79.3	1.43	77.3	.057	35.5
85011801	1006	76.3	1.4	77.2	.057	34.5
85011802	1014		1.39	77.2	.057	35
85011804	996		1.41	77.2	.057	35
85021301	980	71	1.35	77.1	.057	34

DATA SET 5

ID	T2	SLC	GPM	ACFM3	SCFM1C	TEMP1C
01208102	148	0.72	0.221	833	653	296
01208103	148	1.28	0.223	837	665	291
01218102	148	1.02	0.202	834	667	287
01228102	149	0.59	0.189	828	668	298

ID	CS1	SPREFF	SR	DVS	F1	DT
01208102	1620	54.8	1.04	76.2	0.048	31
01208103	1518	69.3	1.95	77.1	0.050	31
01218102	1504	57.8	1.41	75.0	0.050	31
01228102	1531	46.4	0.75	73.2	0.050	31

DATA SET 6

ID	T2	SLC	GPM	ACFM3	SCFM1C	TEMP1C
11078001	123	1.350	0.265	824	671	261
11078002	125	1.010	0.247	807	665	259
11078003	125	0.837	0.232	816	677	262
11068004	122	1.69	0.267	818	680	255

ID	CS1	SPREFF	SR	DVS	F1	DT
11078001	2411	68.3	1.52	80.5	0.044	14
11078002	2416	53.6	1.07	78.7	0.044	15
11078003	2216	55.5	0.89	77.3	0.043	15
11068004	2284	78.2	2	81.1	0.042	16

DATA SET 7

ID	T2	SLC	GPM	ACFM3	SCFM1C	TEMP1C
10138004	130	1.290	0.320	797	648	303
10208001	133	0.815	0.276	817	659	302
10208002	136	1.040	0.273	815	648	306
10208005	129	1.105	0.279	840	663	299
10218005	133	0.590	0.231	814	664	288
10318002	130	0.880	0.227	805	687	294
10318003	130	0.998	0.235	822	680	296
10318004	130	0.998	0.241	812	667	293
10318005	129	1.030	0.265	829	676	287
11058002	127	1.310	0.278	823	662	292
11058003	127	1.110	0.279	819	667	287
11068002	127	0.784	0.264	817	666	296

ID	CS1	SPREFF	SR	DVS	F1	DT
10138004	2353	76.2	1.87	88.2	0.037	16
10208001	2243	78.1	1.05	80.5	0.056	14
10208002	2300	71.6	1.31	80.6	0.054	16
10208005	2333	75.3	1.37	81.1	0.039	14
10218005	2196	35.0	0.64	76.8	0.061	15
10318002	2044	50.6	0.98	76.9	0.058	14
10318003	2212	62.5	1.04	77.7	0.040	16
10318004	2320	61.5	1.07	78.2	0.044	15
10318005	2202	67.2	1.26	80.0	0.046	14
11058002	2319	74.2	1.63	81.4	0.032	15
11058003	2100	72.6	1.52	81.1	0.031	16
11068002	2420	66.5	0.89	79.6	0.040	16

DATA SET 8

ID	T2	SLC	GPM	ACFM3	SCFM1C	TEMP1C
04288201	144	1.10	0.30	880	721	271
04298201	144	0.75	0.28	890	711	273
05068201	140	1.34	0.29	859	729	255
08028206	140	0.862	0.220	907	745	256
08028207	138	0.42	0.228	890	757	254
08068203	140	0.585	0.224	891	732	293
08098203	140	1.11	0.338	888	727	296
08098204	140	0.318	0.207	901	736	293
10228201	138	0.286	0.263	902	734	317

ID	CS1	SPREFF	SR	DVS	F1	DT
04288201	1949	65.6	1.62	86.5	0.057	25
04298201	1923	62.3	1.06	84.6	0.057	25
05068201	1903	67.2	1.93	87.8	0.059	27
08028206	1967	68.3	0.891	80.0	0.060	27
08028207	1943	39.5	0.436	79.5	0.061	25
08068203	2001	54.6	0.616	79.9	0.050	25
08098203	1961	69.6	1.81	89.1	0.044	25
08098204	2012	32.7	0.306	78.0	0.046	24
10228201	2149	43.5	0.33	82.5	0.051	25

DATA SET 9

ID	T2	SLC	GPM	ACFM3	SCFM1C	TEMP1C
07238201	147	1.126	0.250	894	735	275
07278201	150	0.755	0.14	882	744	270
07308201	150	0.377	0.225	895	735	273
08058205	149	0.405	0.138	886	744	255
08068202	151	1.34	0.173	908	744	261
08068206	151	0.853	0.15	908	744	260

ID	CS1	SPREFF	SR	DVS	F1	DT
07238201	2184	53.9	1.207	82.7	0.0547	35
07278201	1723	44.9	0.57	71.6	0.056	36
07308201	1846	29.4	0.43	79.7	0.057	35
08058205	2041	17.5	0.34	76.3	0.068	35
08068202	1916	57.0	1.12	76.1	0.066	35
08068206	1843	32.2	0.64	73.0	0.066	35

DATA SET 10

ID	T2	SLC	GPM	ACFM3	SCFM1C	TEMP1C
08068205	150	0.585	0.213	895	726	299
08098201	150	0.318	0.198	903	733	297
10258202	149	1.05	0.26	879	743	330

ID	CS1	SPREFF	SR	DVS	F1	DT
08068205	2087	42.8	0.566	80.0	0.048	35
08098201	2052	28.7	0.29	77.2	0.044	35
10258202	2146	66.97	1.17	83.5	0.042	35

DATA SET 11

ID	T2	SLC	GPM	ACFM3	SC	TEC
85012501	156.5	.88	.192	849	649	340
85072502	158	.88	.192	833	640	340
85012503	157	.88	.192	831	639	340
85012504	157	.88	.192	825	635	339
85012505	156.5	.88	.192	829	636	340
85012506	157	.88	.192	827	634	340
85012507	157	.88	.192	827	634	340
85012802	159	0	.193	834	655	341
85012803	158.5	0	.192	818	643	340
85012901	159	1.46	.192	837	682	342
85012902	159	1.46	.194	833	682	340
85012903	158	1.46	.195	817	670	340
85012905	157	1.46	.186	810	666	340
85012906	157	1.46	.193	816	669	340
85012907	157	1.46	.19	810	664	340
85013102	161	1.84	.189	835	681	340
85013103	161	1.84	.189	834	681	340
85013103	161.5	1.84	.193	834	681	340
85013104	161	1.84	.191	825	673	339
85013105	161	1.84	.192	827	675	339
85013106	160.5	1.84	.19	819	669	339
85020101	160.5	1.09	.193	790	658	339
85020102	160.5	1.09	.193	790	658	338
85020103	160.5	1.09	.193	792	654	338
85020104	159.5	1.09	.192	797	658	339
85020105	159.5	1.09	.19	788	651	339

DATA SET 11 (Continued)

ID	CS1	SPREFF	SR	DVS	F1	DT
85012501	1890		.95	77.5	.069	33.5
85072502	1951	47.2	.93	77.5	.07	35
85012503	2032		.9	77.5	.07	35
85012504	2040	44.1	.9	77.5	.07	35
85012505	2008		.91	77.5	.07	34.5
85012506	1959	46.4	.94	77.5	.07	35
85012507	2017		.91	77.5	.07	35
85012802	1944		0	76.2	.07	36
85012803	1969	-1.5	0	76.1	.07	35.5
85012901	1964	59.5	1.44	78.2	.054	35
85012902	1990		1.44	78.4	.054	35
85012903	2015	59.1	1.45	78.5	.054	36
85012905	1987	59.4	1.41	77.7	.055	35
85012906	1994		1.45	78.3	.055	35
85012907	2032	61.1	1.42	78	.055	35
85013102	1959	66.9	1.8	78.4	.077	35
85013103	1896	67.3	1.86	78.4	.077	35
85013103	2057	60.7	1.75	78.8	.077	35.5
85013104	1996		1.8	78.6	.078	35
85013105	1979	67.7	1.82	78.7	.078	35
85013106	2004		1.79	78.5	.078	34.5
85020101	1941	51.3	1.13	77.9	.082	34.5
85020102	2003		1.1	77.9	.082	34.5
85020103	1950	52.5	1.14	77.9	.068	35.5
85020104	2034		1.08	77.8	.068	35.5
85020105	2018	54.4	1.08	77.6	.068	35

DATA SET 12

ID	T2	SLC	GPM	ACFM3	SC	TEC
84121801	158	2.05	.187	748	593	341
84121802	158.5	2.05	.19	745	591	340
84121902	158	1.36	.192	733	602	342
84121903	158.5	1.36	.192	727	599	342
84121904	158.5	1.36	.191	728	600	342
84121905	159	1.36	.189	731	602	342
84121907	159	1.36	.19	711	586	342
85021401	160.5	1.89	.185	795	625	335
85021402	159	1.89	.19	785	623	335
85021403	158	1.89	.192	778	618	336
85021404	157	1.89	.192	787	625	334
85022501	159	1.64	.191	770	612	341
85022502	161	1.64	.19	767	612	341
85022503	161	1.64	.191	761	607	341
85022504	161	1.64	.191	771	615	341
85022505	161	1.64	.191	767	613	341
85022506	161	1.64	.191	766	612	341
85030401	160	2.21	.192	779	610	331
85030402	160.5	2.21	.189	777	612	325
85030403	157	2.21	.194	774	614	321
85030404	157	2.21	.189	774	613	321
85030405	157	2.21	.19	772	612	326
85022803	157	2.04	.192	769	609	340
85022805	155.5	2.04	.192	761	606	339
85022804	155.5	2.04	.19	764	607	340

DATA SET 12 (Continued)

ID	CS1	SPREFF	SR	DVS	F1	DT
84121801	2939	53.5	1.51	78.5	.064	35
84121802	2874		1.58	78.8	.064	35.5
84121902	3043	43.1	.98	78.1	.057	35
84121903	3005		1	78.1	.059	34.5
84121904	3068	45.6	.97	78	.059	34.5
84121905	3061		.96	77.8	.059	35
84121907	3178		.96	77.9	.059	35
85021401	2824	59	1.36	78.1	.068	34
85021402	3037		1.31	78.6	.068	35
85021403	2854	59.5	1.42	78.8	.065	35.5
85021404	2633		1.52	78.8	.066	34.5
85022501	2930	53.4	1.2	78.4	.081	33
85022502	2860		1.23	78.3	.081	35
85022503	2922	54.1	1.22	78.4	.081	35
85022504	2823		1.24	78.4	.081	35
85022505	2793	52.9	1.26	78.4	.081	35
85022506	2844		1.24	78.4	.081	35
85030401	2847	57.6	1.68	79.1	.059	35
85030402	2941		1.6	78.8	.061	35.5
85030403	2961	58.3	1.62	79.3	.063	35
85030404	2842		1.65	78.8	.063	35
85030405	2872	70	1.65	78.9	.061	35
85022803	2648		1.67	78.9	.052	36
85022805	2693	51.5	1.65	78.9	.053	34
85022804	2844		1.55	78.7	.052	34